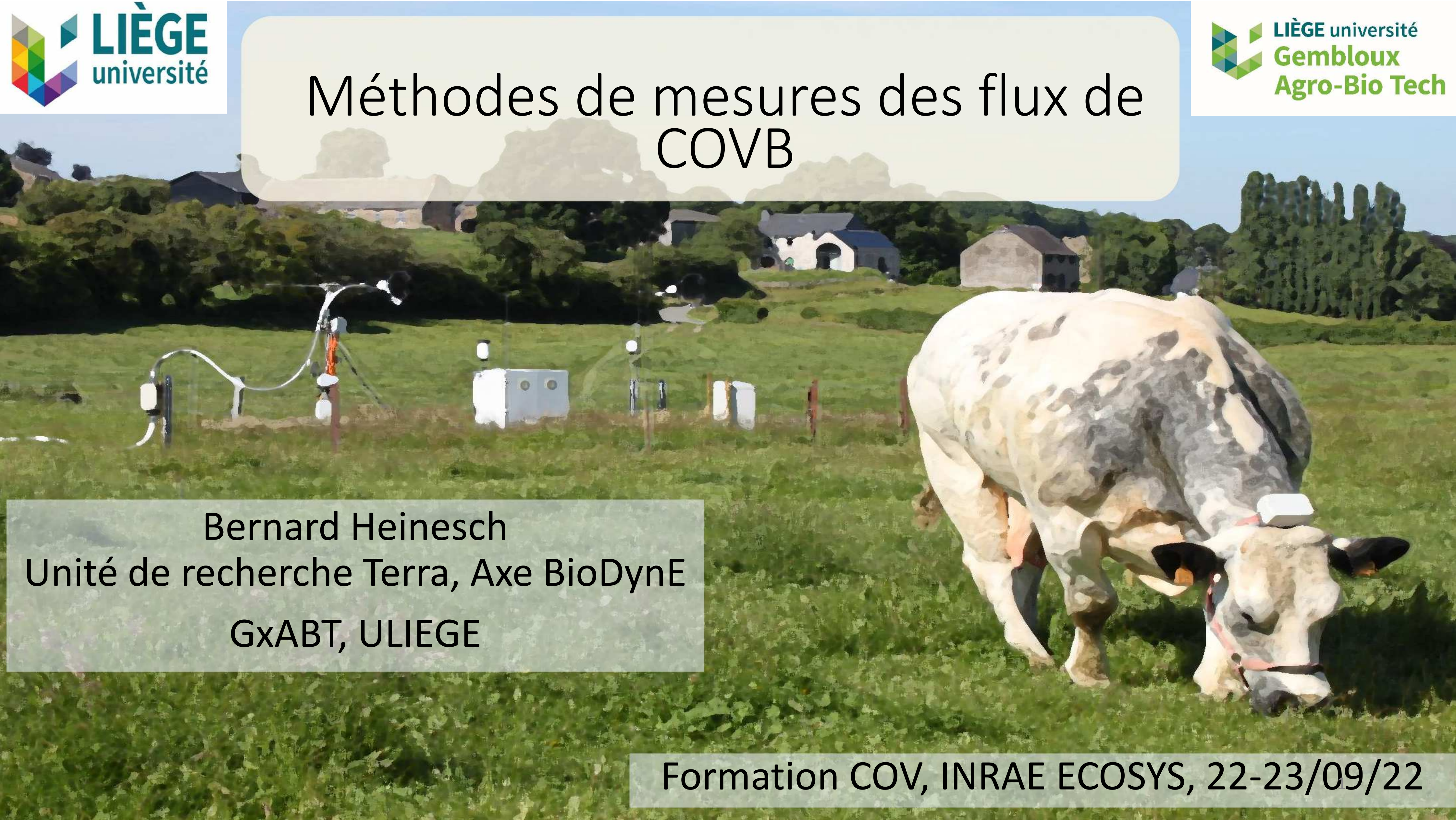
Méthodes de mesures des flux de COVB



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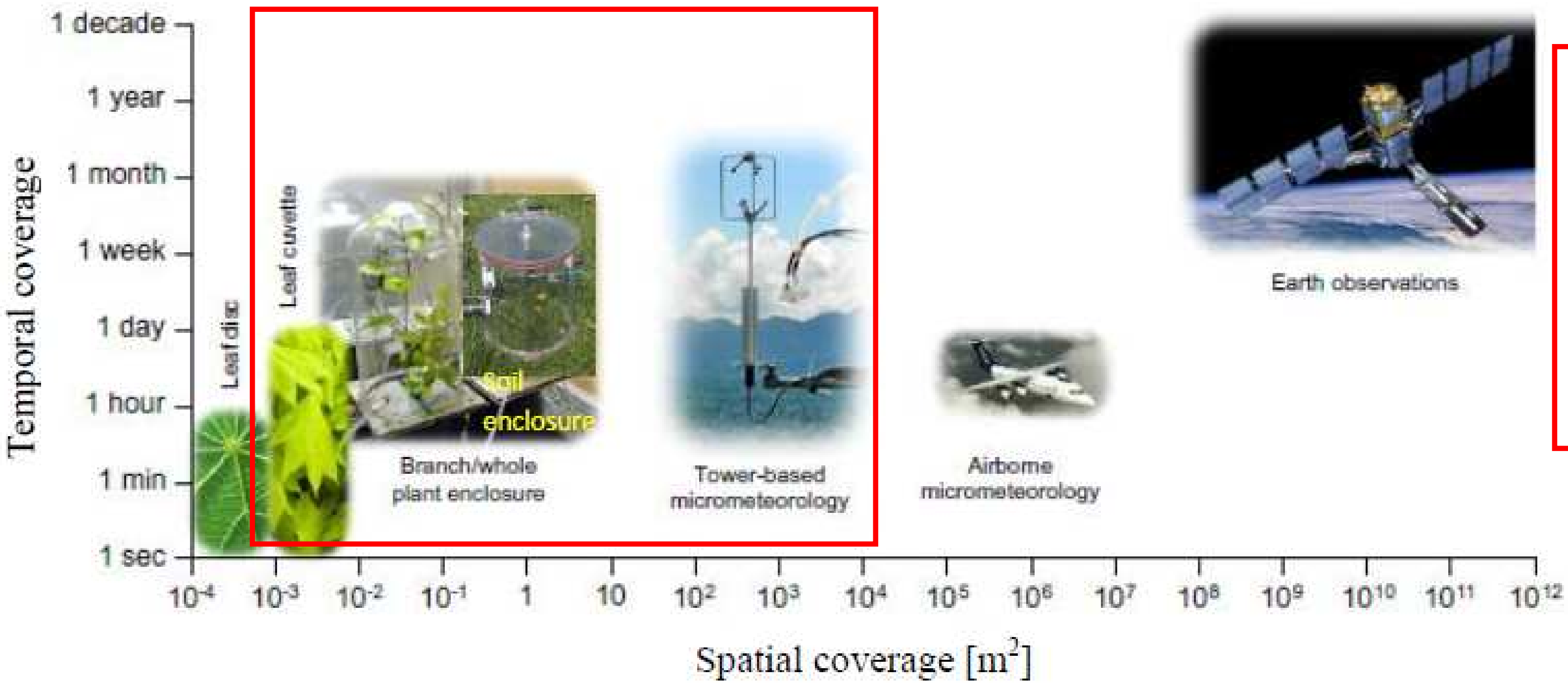
Formation COV, INRAE ECOSYS, 22-23/09/22

Typology of flux measurements



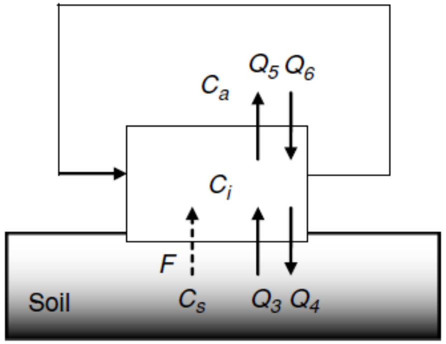
- Enclosures
- Eddy-covariance
- Inversion

(Adapted from Hewitt et al., 2011)

Chamber/enclosure methods (Ecosystem component scale, soil/leaf/trunk)

- Static vs dynamic & closed vs open

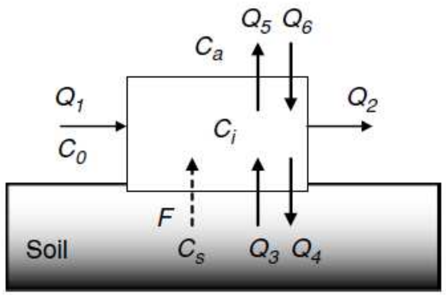
Internal air circulation (dynamic closed): Such systems might be useful for identifying types of BVOC emissions from given plant species, but accurate determination of emission flux rates is extremely difficult with closed systems (Niinemets et al., 2011, BG)



Flow-though (dynamic open)

$$F \; \alpha \; (C_i - C_0) * Q * \frac{1}{A}$$

A : surface (soil/leaves)
Q : flow rate
C_i : conc. in the chamber
C_0 : conc. incoming

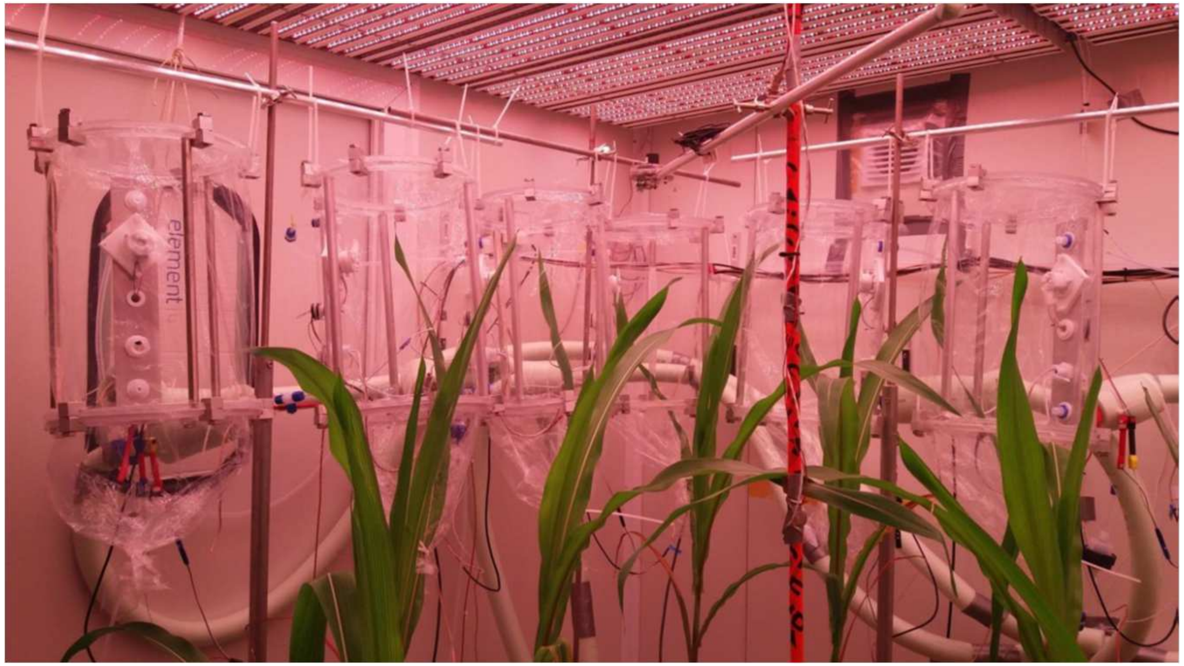


(Pumpanen et al., 2009)

Chamber/enclosure methods (Ecosystem component scale, soil/leaf/trunk)

(Gonzaga et al., 2019)

Chamber/enclosure methods (Ecosystem component scale, soil/leaf/trunk)



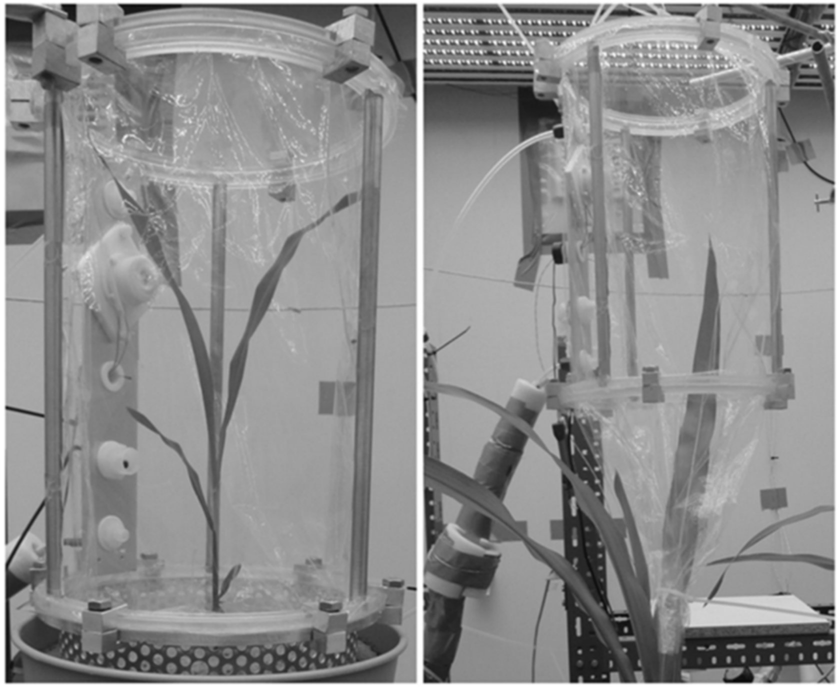
(Mozzafar et al., 2017 & thesis)

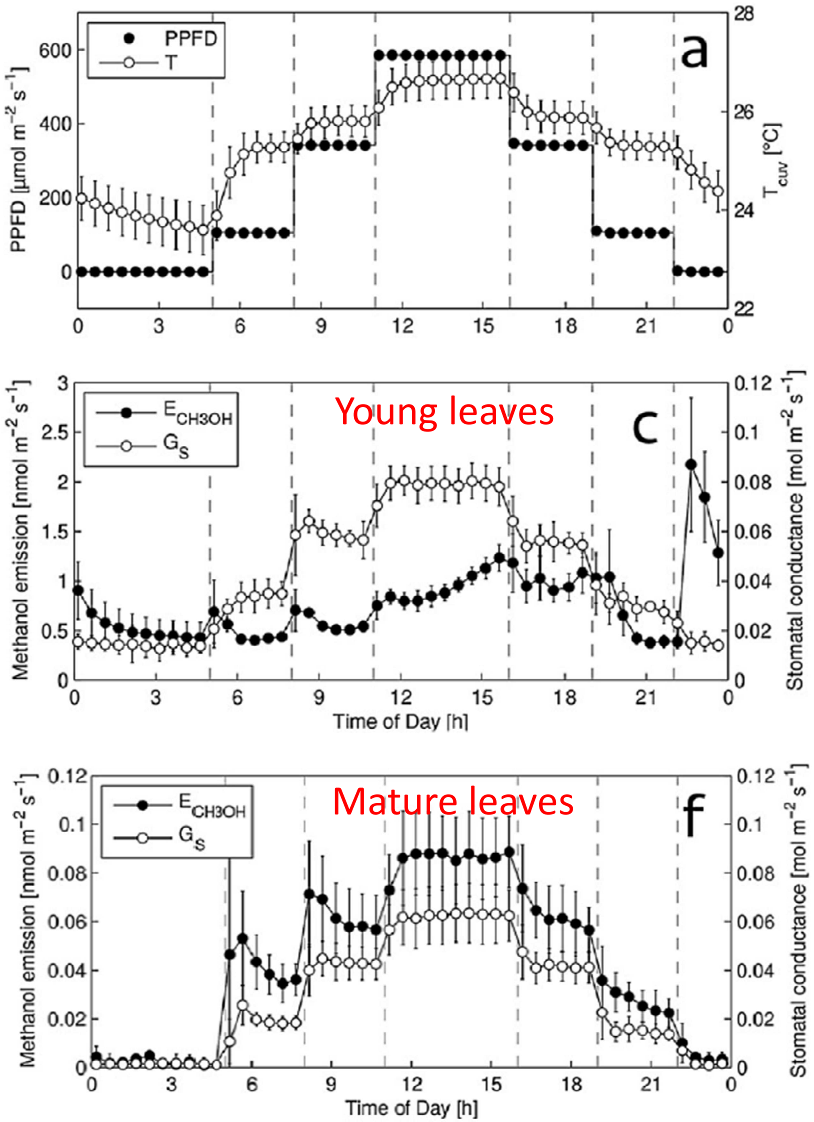
Chamber/enclosure methods (Ecosystem component scale, soil/leaf/trunk)

- Advantages
  - Isolate one ecosystem component
  - Can be used also in controlled conditions
- Challenges
  - Low flowrate (↗ detection limit of exchange rate) vs high flowrate (↗ time response and ↘ modification of ambient conditions/plant physiological status)
  - Reach steady-state conditions
  - Ensure turbulent mixing in the chamber
  - Avoid adsorption on walls and water condensation
  - Depositions might be difficult to reproduce
  - Replicas…

Chamber/enclosure methods (Ecosystem component scale,

- Maize emissions of methanol from young leaves compared to mature leaves

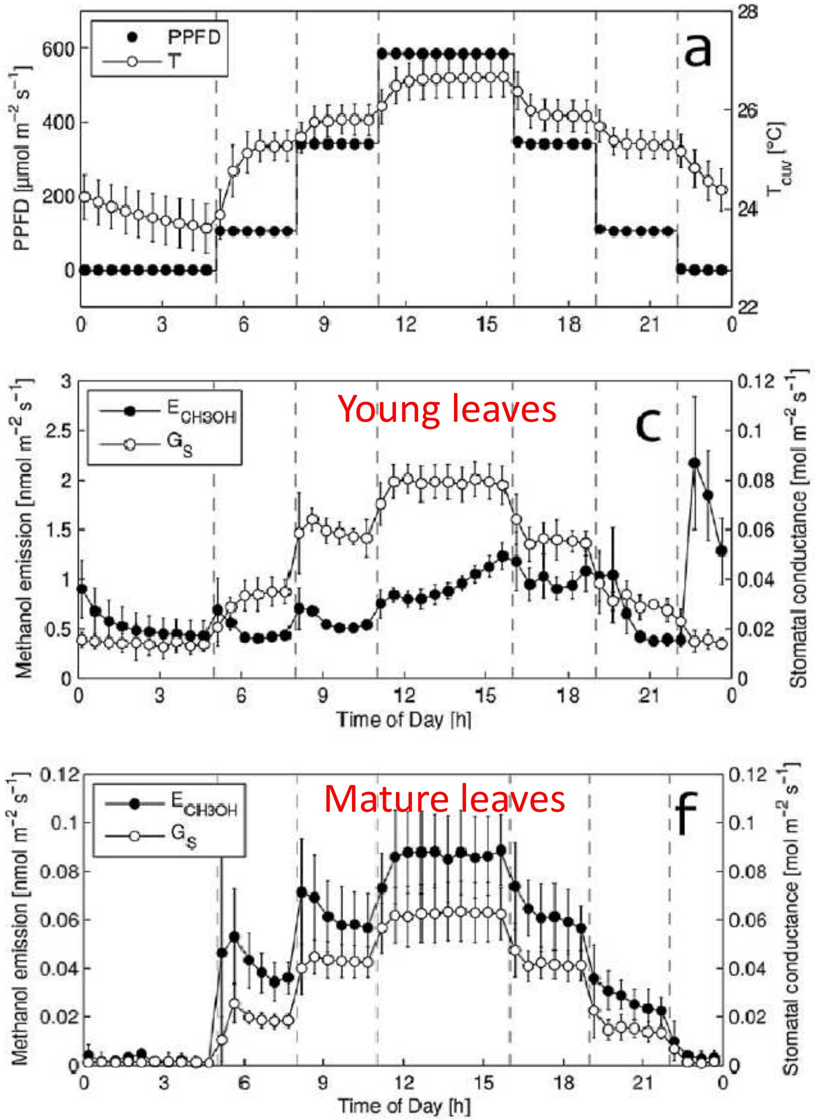




(Mozzafar et al., 2017)

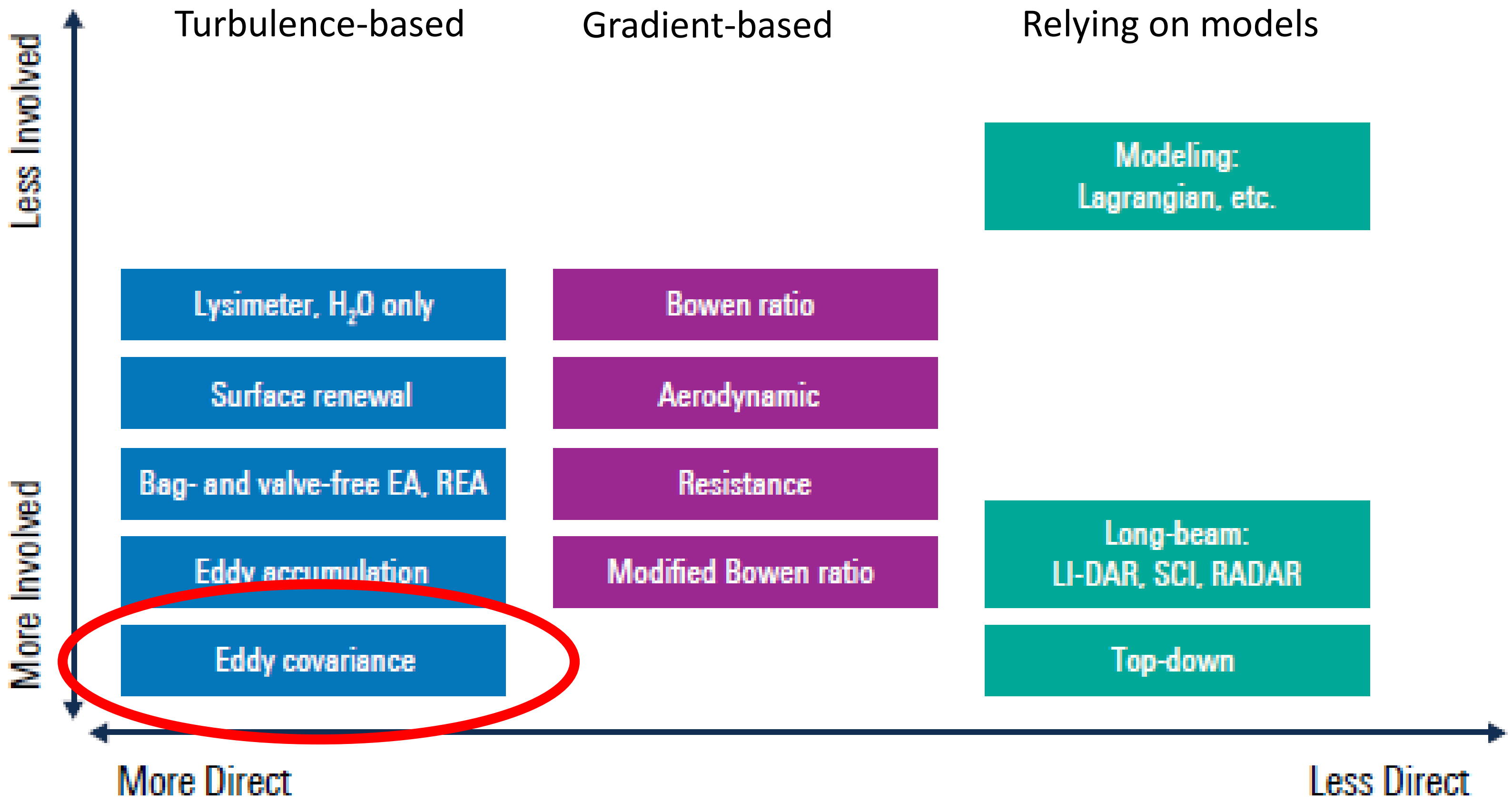
Chamber/enclosure methods (Ecosystem component scale)

- Maize emissions of methanol from young leaves compared to mature leaves
  - YL emit 17 times more than ML (leaf area basis)
  - Curent emission algorithms do not work for YL
  - Burst of emission at light-to-dark transition (guttation ?)
  - Overall low emissions



(Mozzafar et al., 2017)

Micrometeorological methods (Ecosystem scale)

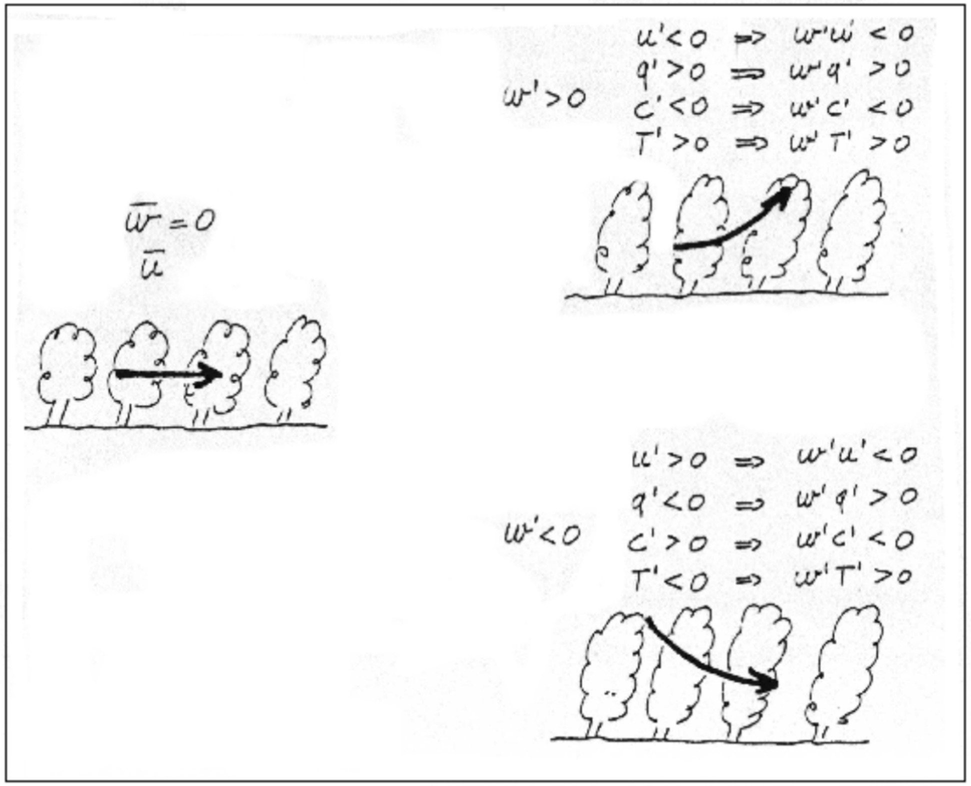


(Adapted from Burba 2022)

Micrometeorological methods (Ecosystem scale)

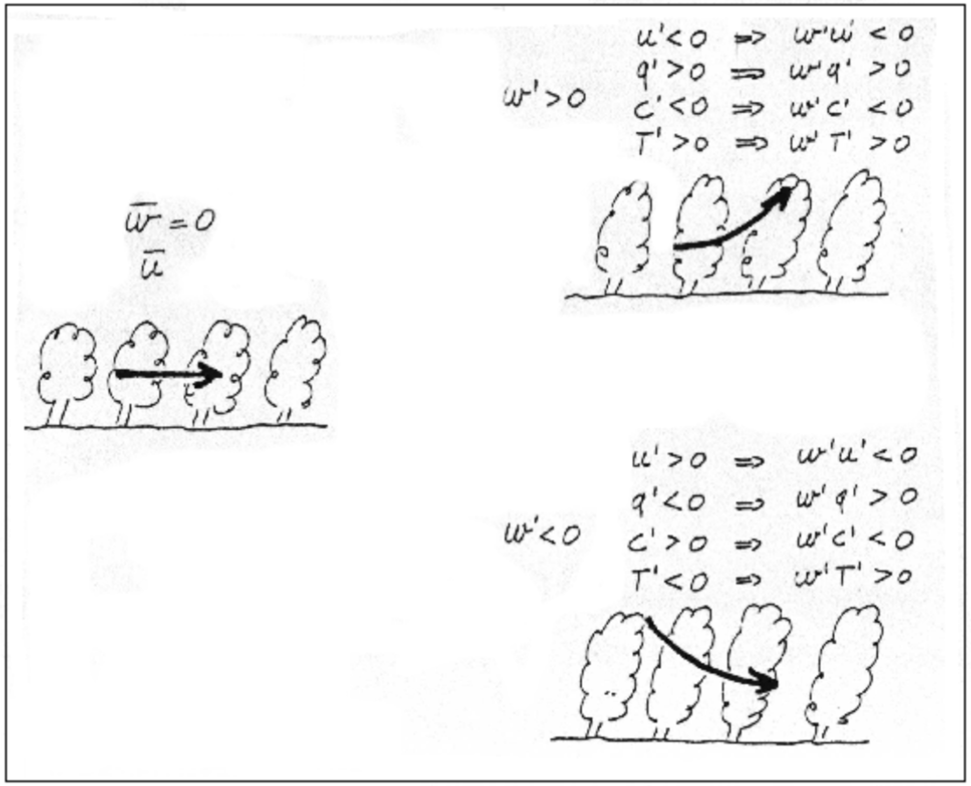
(EC station of Lonzée, Belgium)

Eddy-covariance method



- Primes are the fluctuations (deviations to the mean)
- e.g. photosynthesis at day
  - Eddies will bring CO_2 from the atmosphere to the forest
  - Upward part of eddy : w’ > 0, c’ < 0 => w’ c’ < 0
  - Downward part of eddy : w’ < 0, c’ > 0 => w’ c’ < 0

Eddy-covariance method



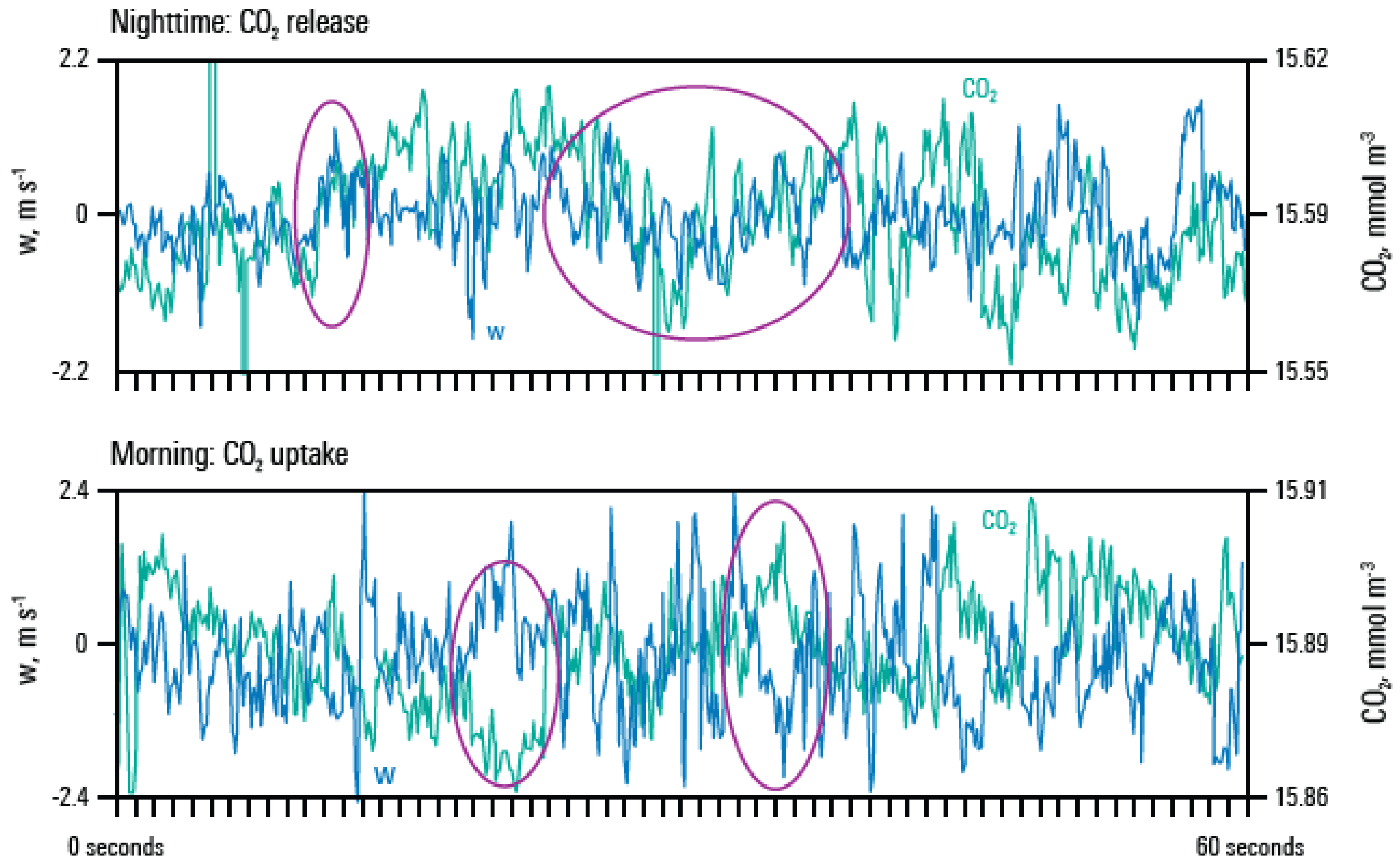
$$\tau_m = \rho\,\overline{w'u'}$$ (momentum flux density)

$$H = \rho C_a\,\overline{w'T'}$$ (sensible heat flux density)

$$LE = L\rho\,\overline{w'q'}$$ (latent heat flux density)

$$F_c = \rho\,\overline{w'c'}$$ (gas flux density)

Eddy-covariance method

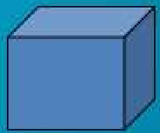


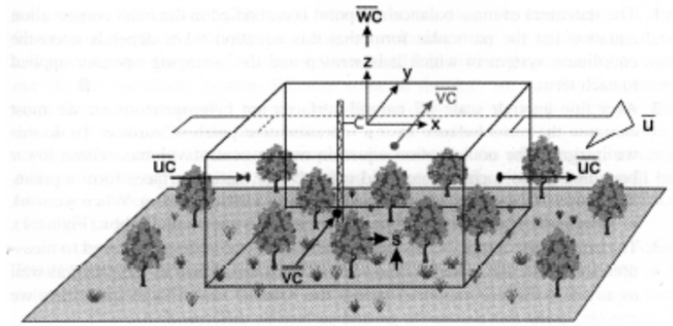
Eddy-covariance method

Eddy-covariance method

- Full derivation of the exchange term comes from the tracer mass conservation equation :

$$\underbrace{\frac{\partial c}{\partial t}}_{I} + \vec{\nabla}\underbrace{(\vec{u}c)}_{II} + \underbrace{K_c \Delta(c)}_{III} = \underbrace{S_c}_{IV}$$

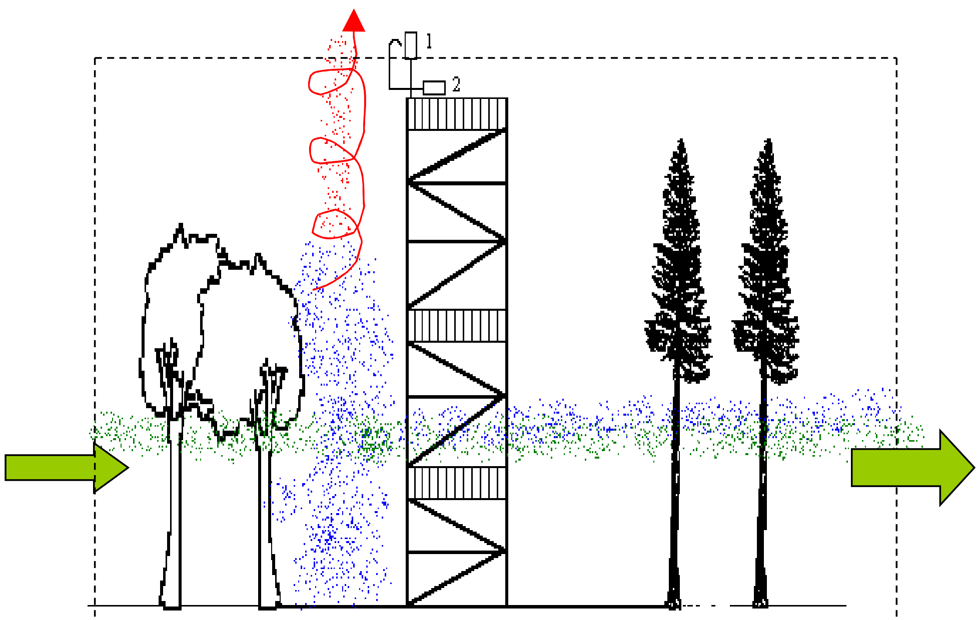




- Decomposition
- Expansion
- Averaging (stationarity)
- Integration

Eddy-covariance method

- Full derivation of the exchange term from the tracer mass conservation equation :



Sources/puits = Flux turbulent +
Stockage +
~~Advection~~

$$\left(\overline{w'\cdot c'}\right)_{h_{eco}} + \int_0^{h_{eco}} \frac{\partial \bar{c}}{\partial t}\cdot dz + \cancel{\int_0^{h_{eco}} \left(\bar{u}\cdot\frac{\partial \bar{c}}{\partial x}\right)\cdot dz} + \cancel{\int_0^{h_{eco}} \left(\bar{w}\cdot\frac{\partial \bar{c}}{\partial z}\right)\cdot dz}$$

- Horizontal homogeneity

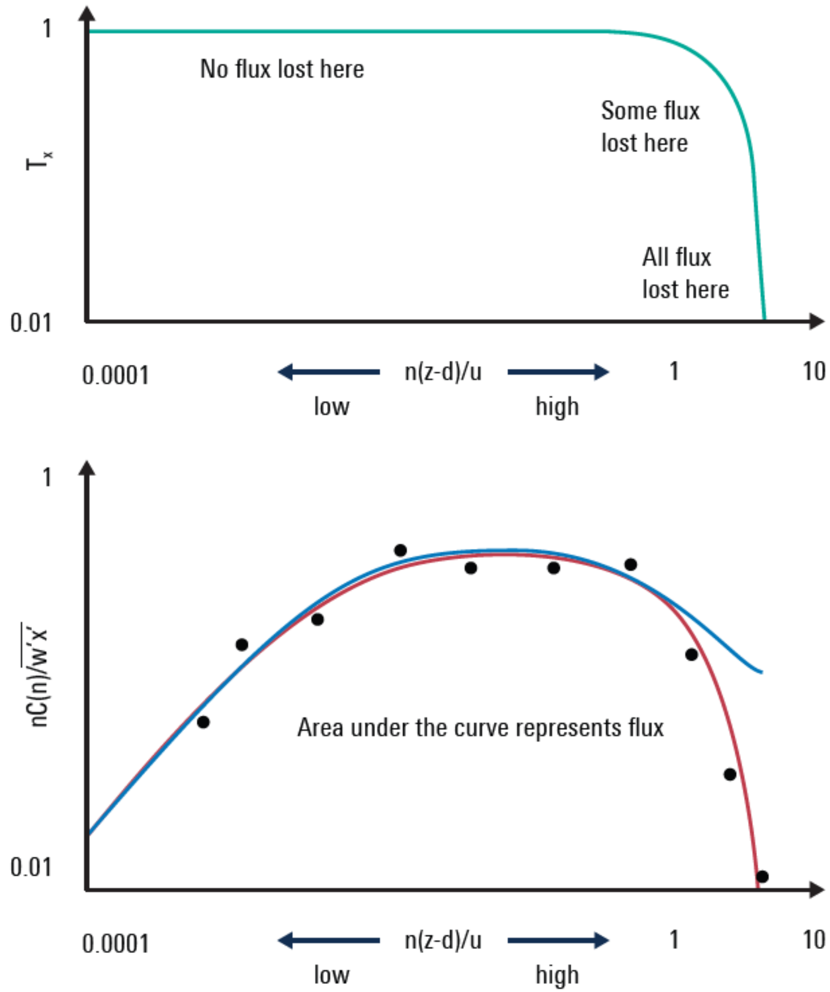
Eddy-covariance method

- Requirements/additional constraints compared to chambers
  - Expensive instrumentation: fast and precise measurements of w and of the tracer, above the canopy.
    - Typically >= 10 Hz but depends on the turbulence frequency content at the site
    - Typically few pptv for VOCs
  - Corrections needed : acquisition set-up must preserve the correlation
    - minimize all kind of frequency loss (damping in the sampling tube, sensor separation)
    - Synchronicity (correct for the unavoidable time-lags)
  - Filtering needed: Filtering spikes, low turbulence, unstationnary events
  - Where is the flux coming from?: Footprint analysis

Eddy-covariance method

- Corrections needed : acquisition set-up must preserve the correlation
  - Tf (acquisition system property) will shift to the left with ↗ tube damping or ↗ sensor separation
  - The cospectra will shift to the right with ↗ U or ↘ z

  => more attenuation



Total Transfer Function:

T_x=1: no flux lost at these frequencies

T_x=0.5: 50% flux lost at these frequencies

T_x=0: 100% flux lost at these frequencies

Cospectra:

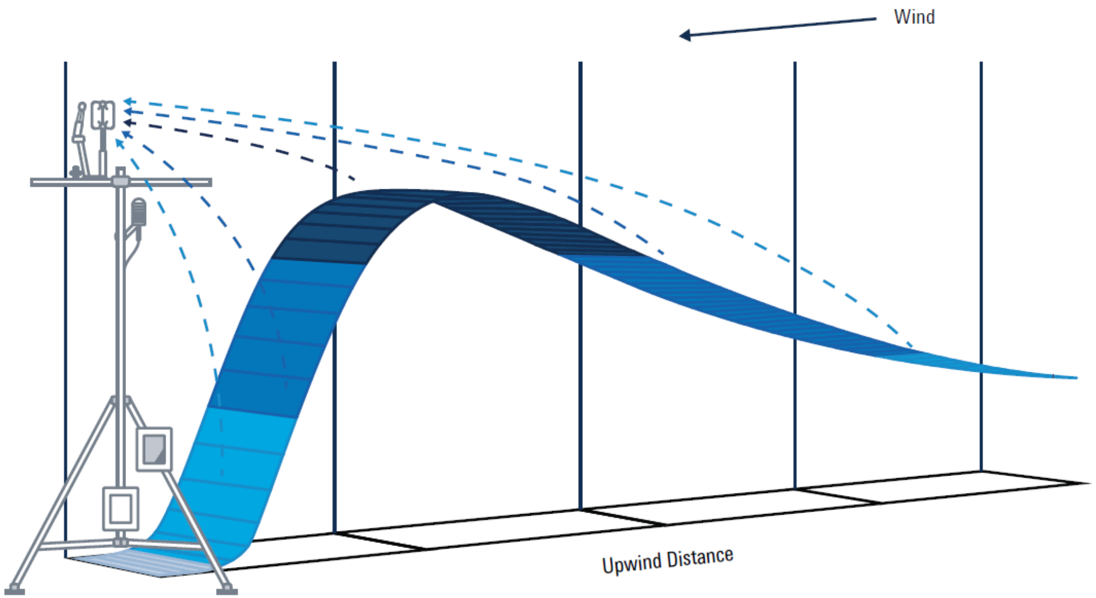
(blue line)	Ideal ($\overline{w'T'}$ is close)
(red line)	Modeled using transfer functions
n	Natural frequency
z	Measurement height
$\frac{C(n)}{\overline{w'x'}}$	Cospectrum / Flux covariance
d	Zero-plane displacement
u	Mean horizontal wind speed
●	Actual H_2O, CO_2, CH_4 flux cospectra

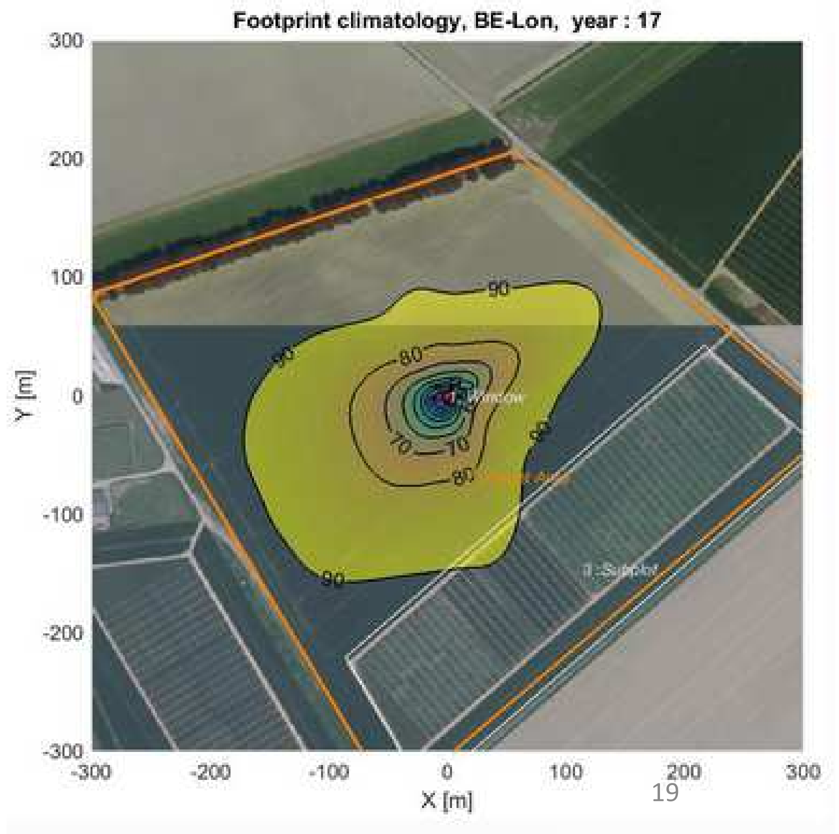
Scales: Logarithmic

Units: Usually non-dimensional

Eddy-covariance method

- Where is the flux coming from?: Footprint analysis
  - Analytical or lagrangian models available
  - One footprint function for each half-hour
  - Can be cumulated to get a « footprint climatology »





Eddy-covariance method

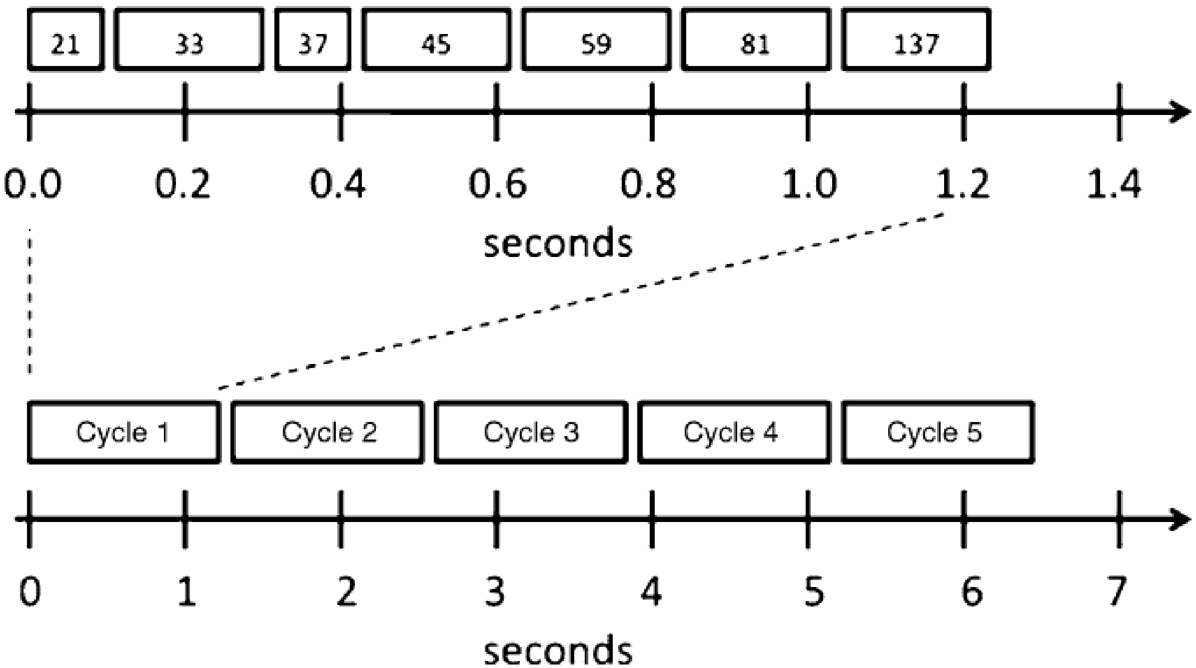
- Requirements/additional constraints for VOCs
  - Design of inlet line to limit high-frequency losses for reactive and soluble compounds
  - Signal-to-noise ratio often low
  - GC-MS too slow
  - Mass spectrometry is fast and precise enough but:
    - Huge number of compounds of interest => PTR-quad-MS with disjunct EC or PTR-TOF MS
    - Compound identification is not always easy
  - What about chemistry between source/sink level and EC level ?
  - No fully integrated packages for QA/QC and flux computation do exist yet

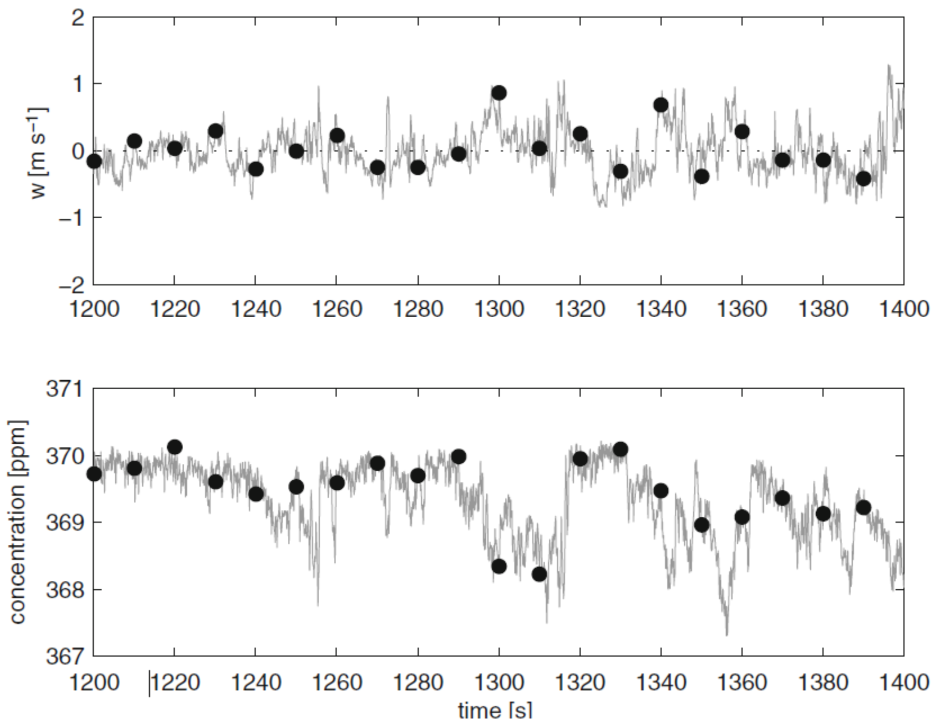
Eddy-covariance method

- Disjunct EC
  - Beginning of 2000's
  - By grab sampler
  - By mass-scanning (virtual disjunct EC): a PTR-MS cycles through several compounds
  - Fewer realizations on the sample population (e.g. response time/sampling frequency of 10 Hz but with a sample interval of 1s)
    - Random uncertainty will increase
    - But no systematic error

Eddy-covariance method

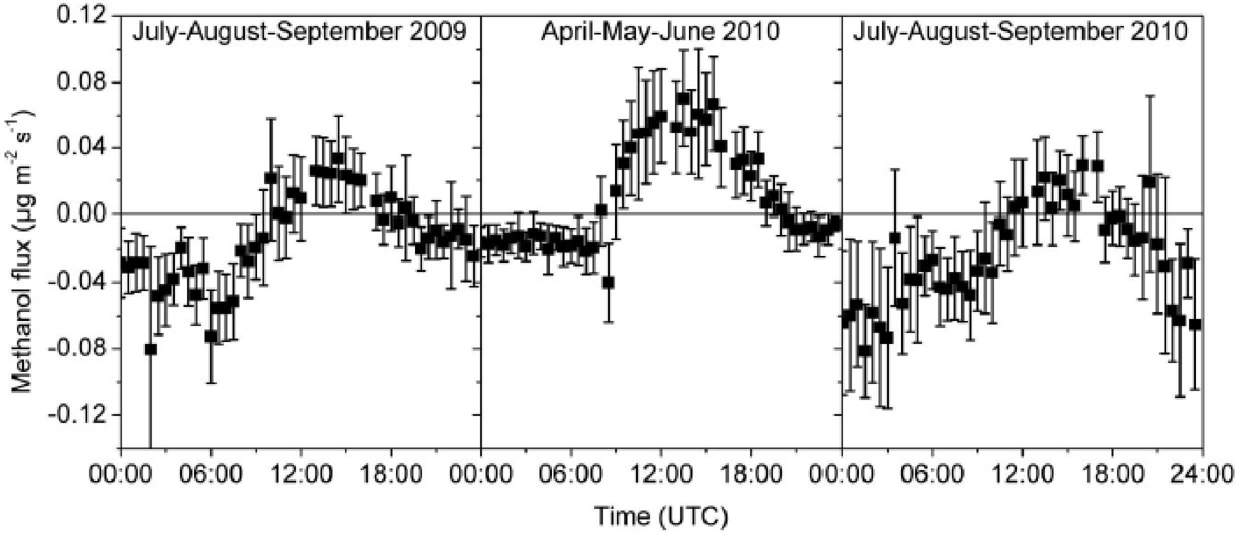
- Disjunct EC by mass-scanning (virtual disjunct EC)

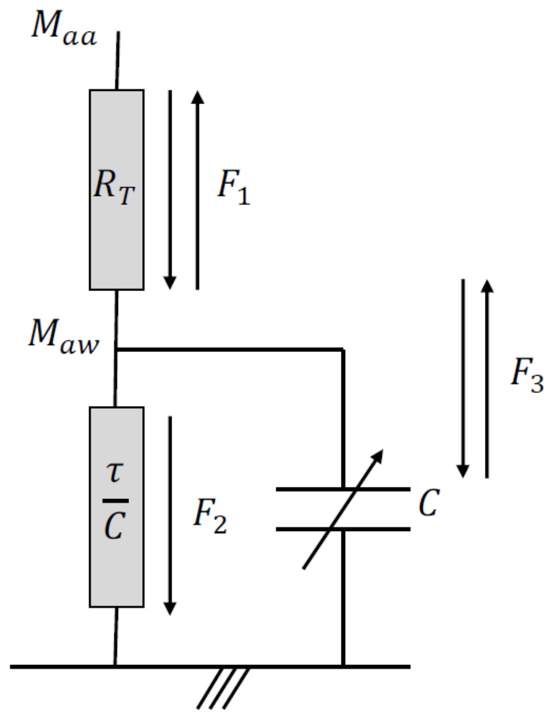




Eddy-covariance method (some results)

- Multi-years of virtual disjunct EC campaign at Vielsalm (BE)
  - Yearly sink of methanol !





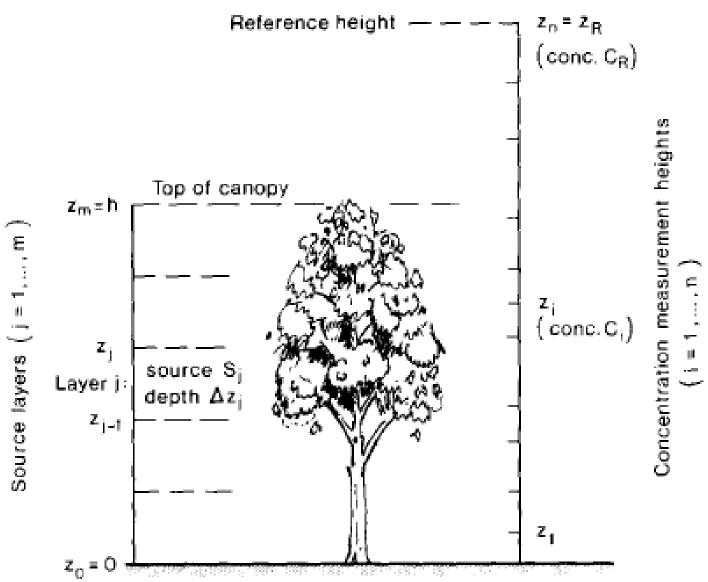
(Laffineur et al., 2012, ACP, « Abiotic and biotic control of methanol exchanges in a temperate mixed forest »)

Eddy-covariance method (some results)

- Ongoing TOF campaign at Vielsalm (BE)
  - Fluxes of ≈400 ions products

Inversion method

- Estimate sources/sinks on the basis of a vertical concentration profile



  - First is the forward approach : predict the concentrations (*c*) knowing the sources/sinks (*q*)
  - A tracer at a given height has a gaussian dispersion
  - If several sources and a time evolution, we end with a dispersion matrix giving the probability that a particle emitted at a given height will propagate to another height

Inversion method

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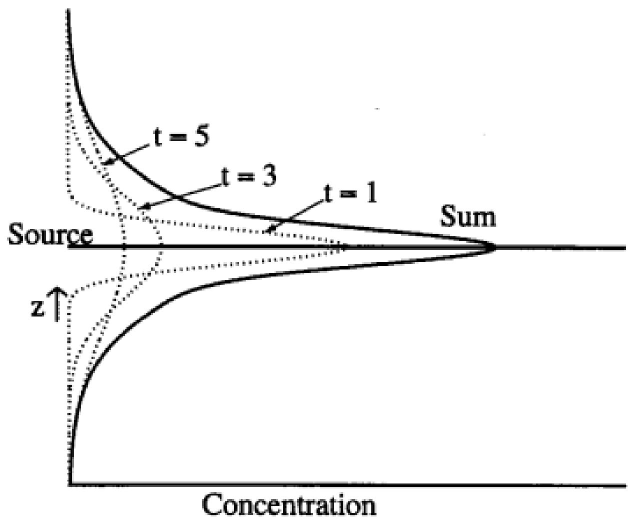


Figure 1. Illustration of continuous plane source. The source is at some height z_s and the puffs that have dispersed for time t add up to the total concentration profile labelled 'sum'.

Inversion method

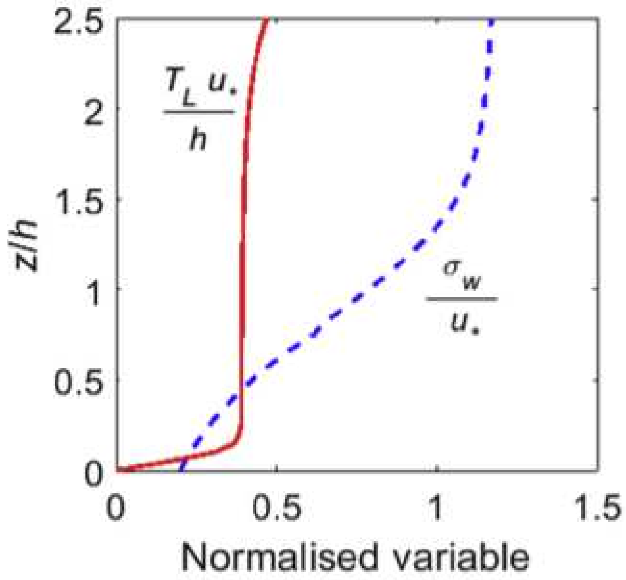
- First is the forward approach : predict the concentrations (c) knowing the sources/sinks (q)

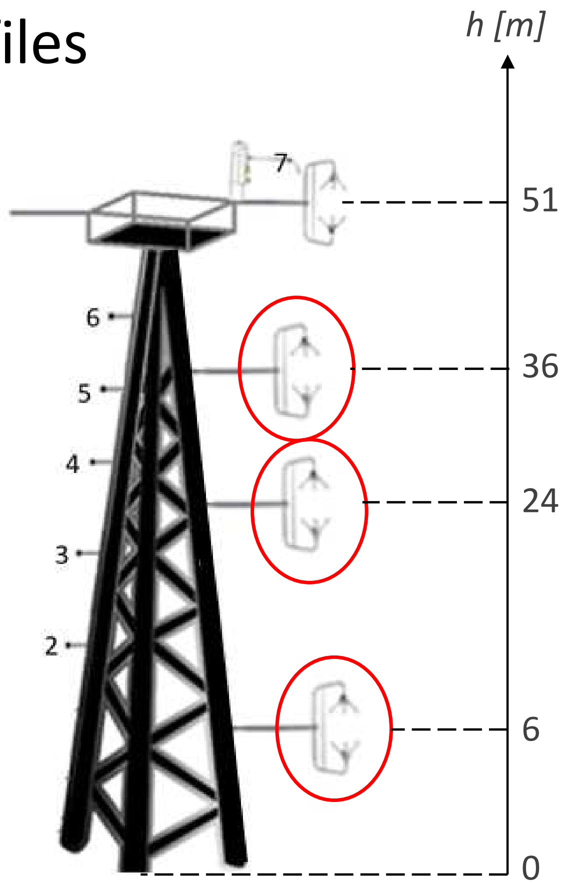
$$\left.\frac{dc}{dz}\right|_i = \mathbf{M}_{ij} q_j$$

$$\mathbf{M}_{ij} = \begin{cases} \dfrac{-\left[1-\exp\left(\frac{-(z_i-z_j)^2}{2\Delta z_j^2}\right)\right]}{2\sigma_{wi}L_{Li}\left[1-\exp\left(-\sqrt{\frac{\pi}{2}}\frac{(z_i-z_j)}{(L_{Li}+L_{Lj})/2}\right)\right]} - \dfrac{\left[1-\exp\left(\frac{-(z_i+z_j)^2}{2\Delta z_j^2}\right)\right]}{2\sigma_{wi}L_{Li}\left[1-\exp\left(-\sqrt{\frac{\pi}{2}}\frac{(z_i+z_j)}{(L_{Li}+L_{Lj})/2}\right)\right]} & \text{for } z_i > z_j \\ \dfrac{-\left[1-\exp\left(\frac{-(z_i+z_j)^2}{2\Delta z_j^2}\right)\right]}{2\sigma_{wi}L_{Li}\left[1-\exp\left(-\sqrt{\frac{\pi}{2}}\frac{(z_i+z_j)}{(L_{Li}+L_{Lj})/2}\right)\right]} & \text{for } z_i = z_j \\ \dfrac{\left[1-\exp\left(\frac{-(z_i-z_j)^2}{2\Delta z_j^2}\right)\right]}{2\sigma_{wi}L_{Li}\left[1-\exp\left(-\sqrt{\frac{\pi}{2}}\frac{(z_j-z_i)}{(L_{Li}+L_{Lj})/2}\right)\right]} - \dfrac{\left[1-\exp\left(\frac{-(z_i+z_j)^2}{2\Delta z_j^2}\right)\right]}{2\sigma_{wi}L_{Li}\left[1-\exp\left(-\sqrt{\frac{\pi}{2}}\frac{(z_i+z_j)}{(L_{Li}+L_{Lj})/2}\right)\right]} & \text{for } z_i < z_j, \end{cases} \quad (21)$$

M depends on 2 variables describing the turbulence : σ_w (standard dev of vertical wind speed) and L (Lagrangian lenght scale)

- Theoretical/experimental turbulent profiles

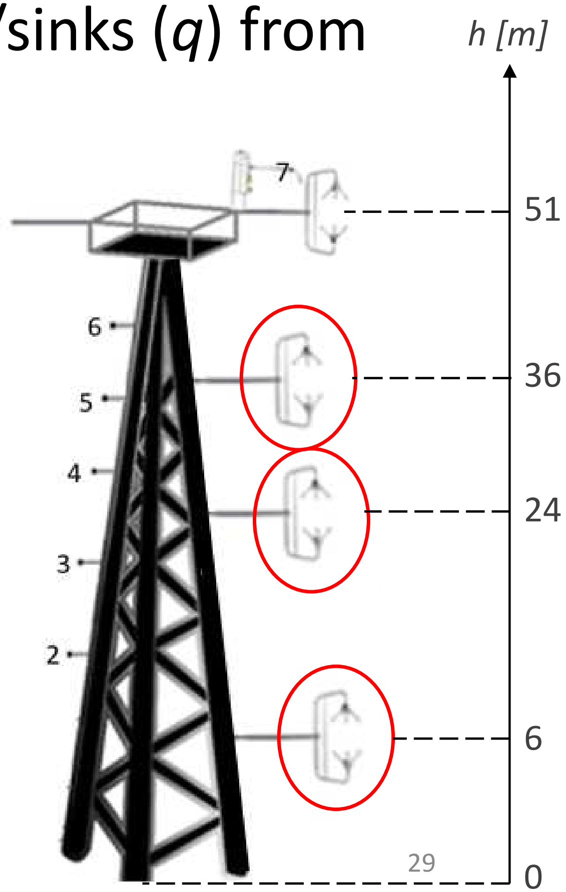


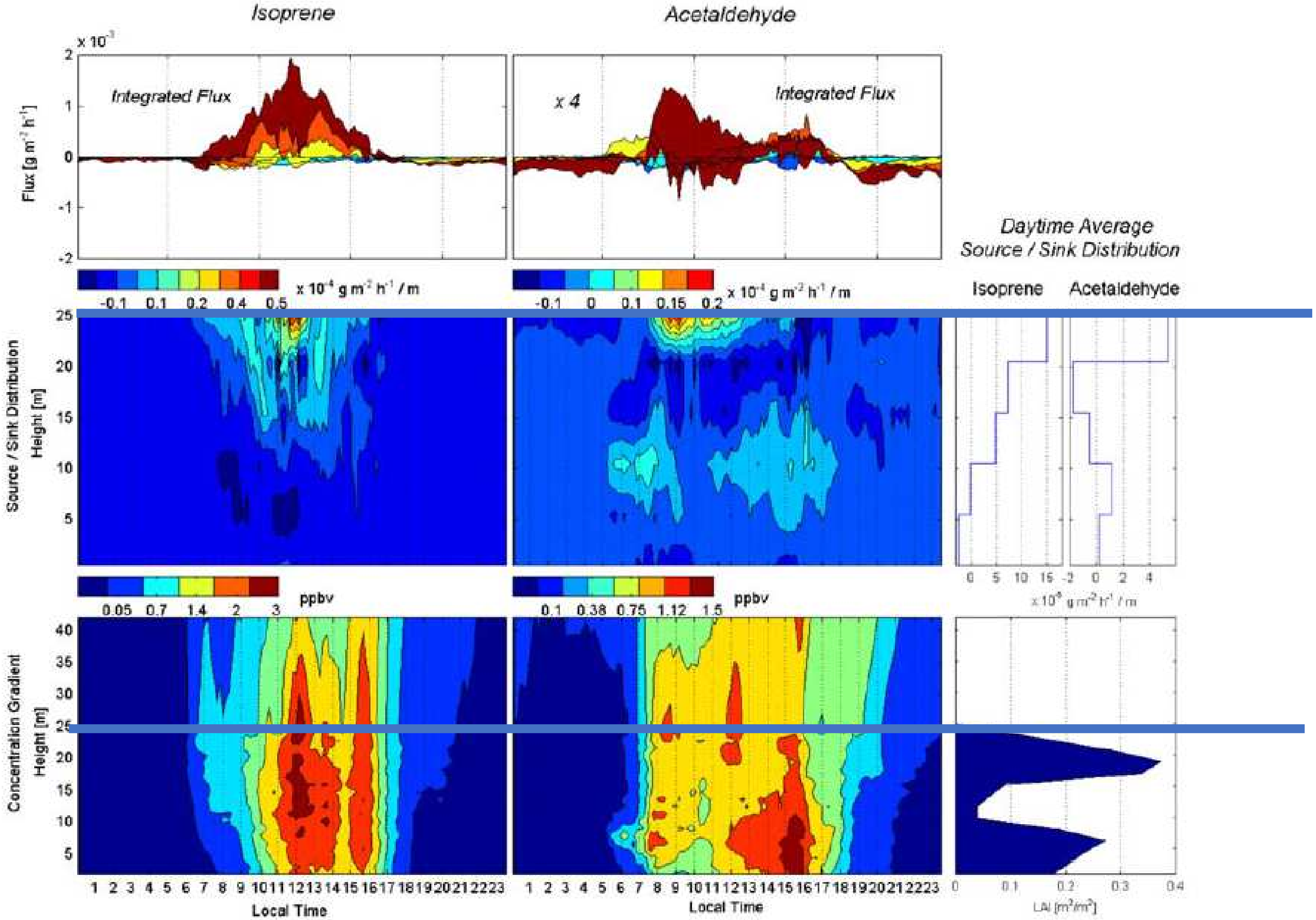


Inversion method

- Then the equation can be inverted to get the sources/sinks (*q*) from the concentrations (*c*) (backward approach)
- Appealing method but
  - 1D…
  - uncertainty can be important in night conditions (turbulence not well developed)
  - can be (very) sensitive to [] measurement errors
  - nb of source/sinks levels < nb of [] levels
  - Can be numerically unstable

- OK but still…

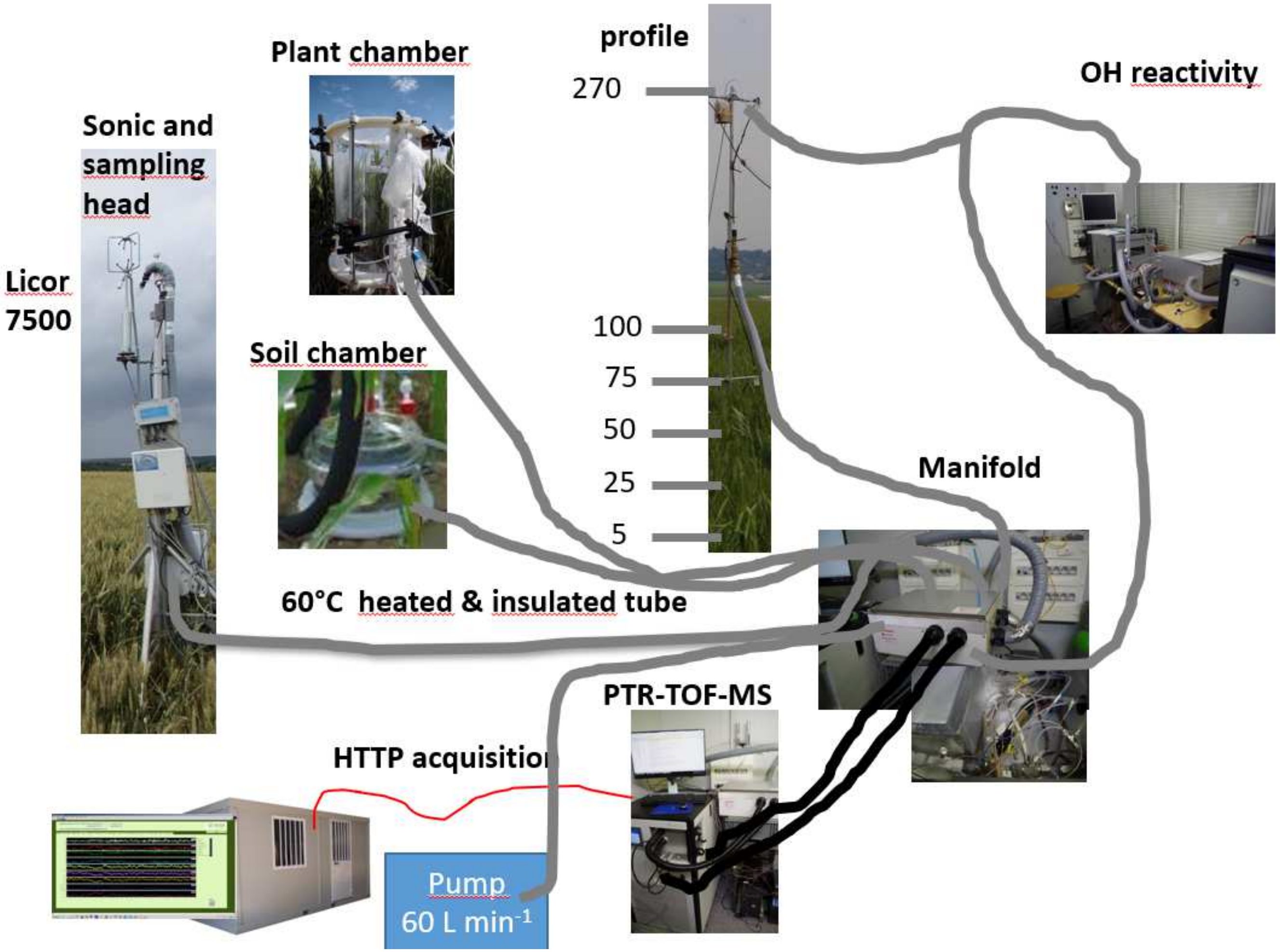




(Karl et al., 2004, on a tropical forest with a dolly profile system)

A golden set-up

- Combined
  - enclosures
  - EC
    - above canopy
    - why not in-canopy
  - inversion…



(FR-Gri, COVER campaign, comm. pers Buysse P.)